Simplified Models for Particulate Dispersion in Buildings

Contract #: 500-02-004; MR-043-08
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Department of Mechanical and Aerospace Engineering
Contract Amount: $75,000
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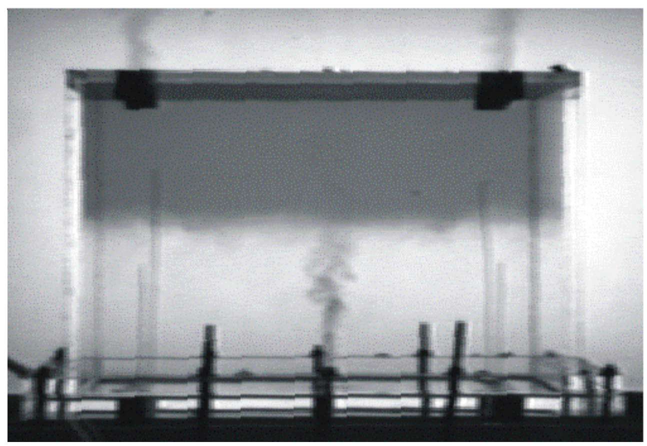
The Issue

Maintaining the internal temperature of buildings in a comfortable range accounts for a significant proportion of the total annual energy consumption of the United States (approximately 9% or 8.6 quadrillion BTU, costing about $90 billion per year).[1] As construction in relatively hot parts of the country is projected to increase markedly over the coming years, particularly in California, there is a pressing need to identify energy-efficient ways to cool buildings satisfactorily.



Small-scale Plexiglas room model showing natural displacement ventilation

Various low-energy systems such as displacement ventilation, underfloor air distribution, natural ventilation, and hybrid ventilation are under consideration. Most of these ventilation strategies rely on stratifying a space and extracting the warmest, most uncomfortable air, thus making these methods more efficient than conventional mixing ventilation. However, in order for these systems to be successful, it is vital that they provide adequate levels of indoor air quality (IAQ) along with comfortable temperature and humidity. The introduction of outside air, either through filters or simply by opening a window, introduces outside pollutants. At the same time, internal pollutants are generated and need to be extracted from the building.

The success of alternative ventilation strategies depends on the ability to predict the internal environment and to assess the resulting IAQ and comfort, as well as the potential energy savings. This project expands capabilities in modeling contaminant distribution and transport within energy-efficient buildings, so that designers and engineers can have confidence that their buildings will perform appropriately.

[1] Energy Information Administration, 2000.

Project Description

Contaminants come in two forms: passive tracer types (gases and aerosols) and particulates (airborne solids). This project—funded by PIER's Environmental Exploratory Grants Program—investigated both forms using a combination of experimental and numerical modeling.

The project team developed analytical and numerical models aimed at capturing the behavior of passive tracer and particulate contaminants in stratified spaces.

The models were validated on the basis of small-scale experiments in a Plexiglas room model. These small-scale studies examined passive tracer gases and particulates, including effects such as settling velocities, deposition, resuspension, and coagulation.

Model predictions for particulate behavior were further refined through complementary experiments in a full-scale room. Particulate contaminants of a known size distribution were released and measured using laser-induced breakdown spectroscopy (LIBS). Results were compared with the model predictions.

Using all the results gathered from experiments and analysis, the project team has developed a simplified, semi-analytical model. The plan is that this model can be effectively and easily used as a design tool by building engineers in order to create low-energy ventilation schemes that also provide adequate levels of IAQ.

PIER Program Objectives and Anticipated Benefits for California

This project offers numerous benefits and meets the following PIER program objectives:

- **Environmentally sound, safe, reliable, and affordable energy products.** The results of this research will help architects and engineers to specify energy-efficient cooling systems. By reducing demand for electricity, such cooling systems will reduce power plant emissions, increase system reliability during the summer peak demand hours, and lower cooling bills.
- **Improved public health.** A better understanding of the motion of contaminants and particulates within a building will help improve ventilation systems for better public health.

Results

By representing heat sources as ideal sources of buoyancy, simple analytical models allowed comparison of the average efficiency of contaminant removal by energy-efficient displacement systems vs. traditional HVAC systems.

In the various displacement scenarios, peak concentrations of contaminants—both passive and particulate—occurred at the thermal interface between the upper and lower layers. Depending on the location of this interface, people sitting down may be in the clean lower layer, while those standing up may have their heads at the peak contaminant concentration zone. As such, the height of the thermal interface is not only important to occupant comfort, but also becomes a critical parameter in designing a building for indoor air quality, since it appears to be imperative to locate the interface above head height.

Care must be taken when choosing the optimum ventilation strategy. Depending on contaminant size and source location, certain energy-efficient HVAC systems can outperform traditional systems in removing contaminants. However, in other scenarios, traditional systems expose occupants to lower levels of contaminants.

Studying only the average amount of contaminant in a space can be very misleading, as displacement ventilation can result in nontrivial vertical gradients in the contaminant field. Thus, while the average concentration in a space may be within acceptable standards, specific locations may exceed standards and expose occupants to undesirable levels of contaminants.

Final Report

The final report for this project can be downloaded from www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2007-098.

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